Exploring the Evolution Structure of Process Modelling for Industry 4.0: a Science Mapping for Proposing Research Paths

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Abstract

Companies still concern about the impacts of the technologies of industry 4.0 in business processes. Hence, researchers are trying to develop studies to improve the understanding related to new techniques, frameworks, and concepts in order to support the implementation of industry 4.0. The aim of this paper is to perform a science mapping in the area of process modelling for industry 4.0 in order to get a holistic observation through the evolution structure of the field of study, pointing the main challenges, trends and suggestions for future works. To perform this science mapping, the SciMAT was used. Moreover, the VOSviewer was used to analyze co-authorship between authors. The scientific evolution presented 17 clusters in which the most representative themes are: 'design', 'framework' and 'cloud computing'. Besides, the intellectual structure of motor themes is presented as well as the main challenges, trends and suggestions for future researches.

Keywords

Process Modelling, Business Process, Industry 4.0, SciMAT, Science Mapping.

1. Introduction

The concept of industry 4.0 that emerged in Germany in 2011 as a technological strategy (Bauer 2015; Tortorella et al. 2020) is projected to grow by $ 310 billion until 2023, and is expected to bring emerging technologies to 60% of global companies, driving the development of new services and tasks in organizations (Kumar and Iyer 2019) and transforming the business and manufacuring processes (Cobo et al. 2018). These changes highlight the need for interconnectivity and interoperability (Tidrea et al. 2019) to enable monitoring and control of operational processes (Reis et al. 2018; Kipper et al. 2019a). The pursuit of such technological integrations has led countless companies to redesign business processes as a strategy to get the maximum benefits of the digitalization (Fynes et al. 2015). Such technological integrations reshape the workflow in pursuit of flexibility in the execution of processes (Seiger et al. 2015), creating the need for further studies in the development and management of products, services and processes (De Oca et al. 2015; Kipper et al. 2019).

In this context, although there are several languages to model organizational processes, some stand out for their ease of use or the possibility of representing different activities and tasks, such as: Business Process Model and Notation (BPMN) (Arévalo et al. 2016; Zarour et al. 2019; Furstenau et al. 2019), Yet Another Workflow Language (YAWL) (Van der Aalst and Ter Hofstede 2005; Alissa et al. 2018), Petri Nets (Zhou and Wu 2018; Ahmed and Majid 2019), Event-driven Process Chain (EPC) (Van der Aalst 1999; Amjad et al. 2018), Unified Modelling Language (UML) (Rumbaugh et al. 2004; Smith et al. 2019; Smith and Owens 2019), among others. However, there are different perspectives on the use of process modelling for industry 4.0. While some authors argue that traditional modelling languages are incompatible with smart factories (Seiger et al. 2015), others develop extensions of these languages for smart environments (Du et al. 2018; Cheng et al. 2019).

Several authors have been explored deep this field of research, such as: Dani et al. (2019) that reviewed 10 years of Visualization of Business Process Models, but they did not relate to industry 4.0; Savastano et al. (2019) showed the impacts of digital transformation on industrial processes; Tupa et al. (2017) presented a review relating Business Process Management and industry 4.0; and Wortmann et al. (2019) conducted a systematic mapping study to understand the use of modelling languages in industry 4.0. However, no study performed an evolution structure of the field of research. This paper presents a scientific mapping of the process modelling for industry 4.0 in order to get a holistic observation through the evolution structure of the field of study, pointing the main challenges, trends and suggestions for future works that may help professionals and researchers in understanding and implementing process modelling for smart factories.

2. Methodology and Dataset

This work is characterized as a science mapping supported by the SciMAT software developed by Cobo et al. (2012), the criteria used in this study are presented as follow. For the type of documents we selected 'article' and 'review' of the Web of Science database, in English only, published since 2011, because the appearance of the Industry 4.0 concept (Kagermann et al. 2013). The search was carried out considering the following terms for industry 4.0: (“industrie 4.0” OR “industry 4.0” OR “digital manufacturing” OR “smart manufacturing” OR “smarter manufacturing” OR “intelligent factory” OR “smart production” OR “intelligent factories” OR “the fourth industrial revolution” OR “the 4th industrial revolution” OR “smart factory” OR “smarter factories” OR “smart factories” OR “factory of the future” OR “factories of the future ” OR “factory-of-things” OR “real-time manufacturing” OR “real-time factory” OR “ubiquitous factories” OR “ubiquitous manufacturing” OR “ubiquitous factory”) used in the reviews by Strozzi et al. (2017), Liao et al. (2017), Buer et al. (2018), Kipper et al. (2019) and Wortmann et al. (2019). Regarding process modelling, the following terms were considered: (“modeling language” OR “modelling language” OR “business process modelling” OR “model business process” OR “business process” OR “process model*” OR “business process management” OR “workflow” OR “choreography” OR “orchestration”) mentioned in studies of Alotaibi and Liu (2017), Pourmirza (2017), Wortmann et al. (2019) and Dani et al. (2019). The 91 articles exported from the database were divided into 3 subperiods to create the thematic evolution of the area (2011 - 2015; 2016 - 2018; 2019 until 01/08/2020). Finally, keywords with the same meaning as ‘process modeling’ and ‘process modelling’ were grouped. In addition, the keywords used to search the databases were removed, as we wanted to find unknown concepts. The steps of the scientific mapping are presented in Figure 1 (for more information see Cobo et al. (2012) and examples in López-Robles (2019) and Kipper et al. (2019)). Besides, to generate the co-authorship network we used the software VOSviewer developed by Waltman and Van Eck (2012).

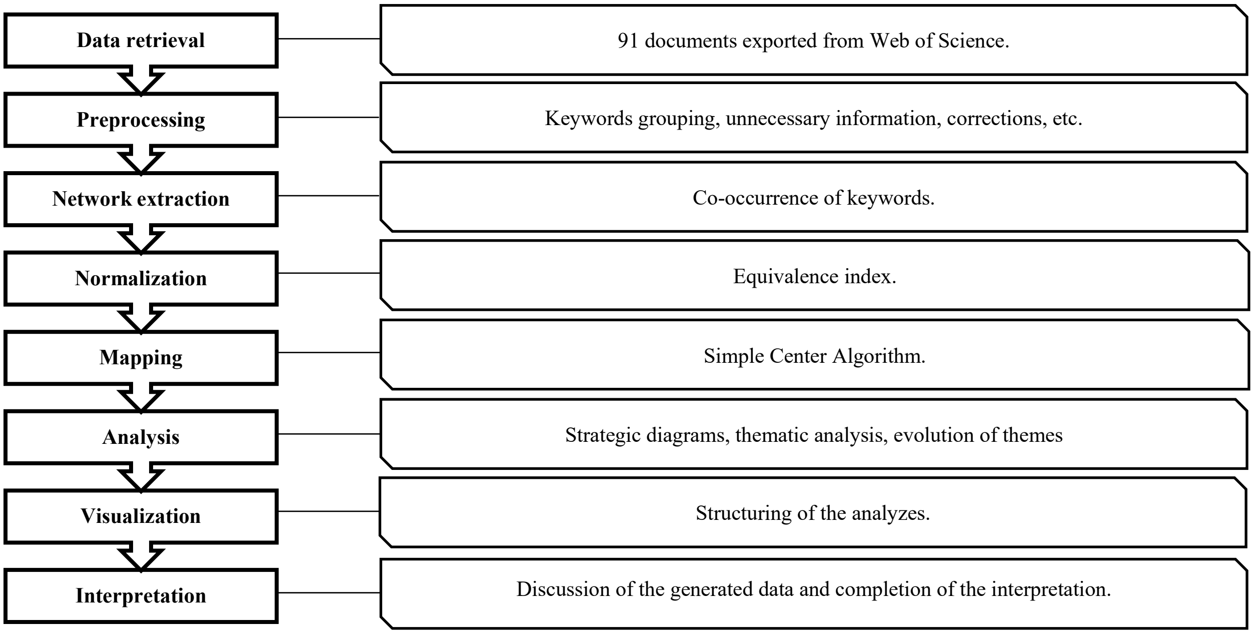


Figure 1. Workflow of science mapping (Source: Adapted from Cobo et al. 2012).

3. Analysis of data and discussions

Figure 2 shows the number of publications of the process modelling for industry 4.0. It can be seen that in the early years, few documents were identified relating the terms. In 2015, the growth of research in the area becomes exponential, reaching 38 documents in 2019, while in 2020 4 related documents have already been identified due to the data collection (01/08/2020). The significant increase in the number of researches relating to process modelling and industry 4.0 highlights the growing concern with the theme and its importance in the era of the fourth industrial revolution.

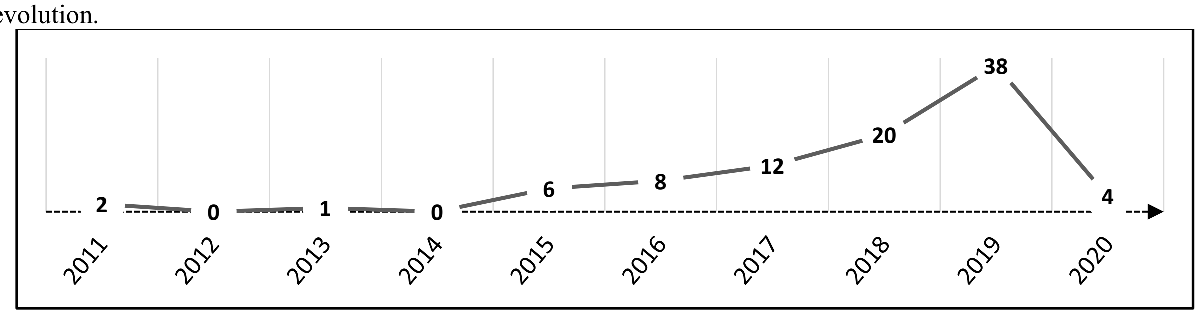
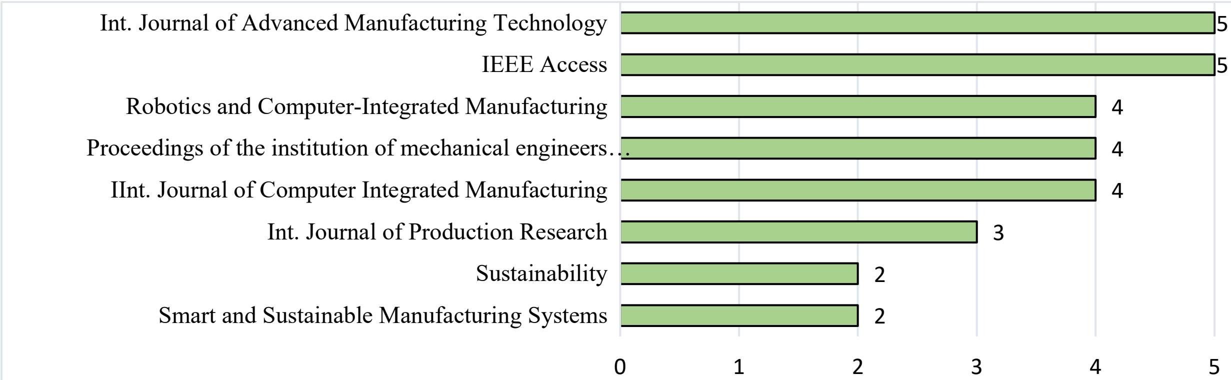


Figure 2. Number of publications over time (2011 – 2020).

Figure 3 shows the journals that publish studies relating process modelling for industry 4.0. The International Journal of Advanced Manufacturing Technology and IEEE Access are the journal that has the largest number of publications, followed by Robotics and Computer-Integrated Manufacturing, Proceedings of the institution of mechanical engineers part B-Journal of Engineering Manufacturing and International Journal of Computer Integrated Manufacturing. Nevertheless, the journal with the highest SCImago Journal Rank (SJR) is Robotics and Computer-Integrated Manufacturing with 1.41. The SJR indicates the journal's scientific impact factor (Falagas et al. 2008). Publications in such journals, whose scientific impacts (SJR) are high, demonstrate the importance and necessity of studies related to the field of research.

Figure 3. Journals that publish studies to industry 4.0 related with process modelling (Source: Scimago and



SciMAT).

In Figure 4 is presented the co-authorship network of authors. It is possible to identify that Zhang, Xu and Marrela have the largest amount of scientific production and they are key researchers for the field of study. Besides, there are other more uniform networks such as Cala, Zobel-Roos, Qu, among others. However, these networks are still young because the network of authors do not yet relate to other networks, which presents a future need to develop the field of study of process modelling for industry 4.0.

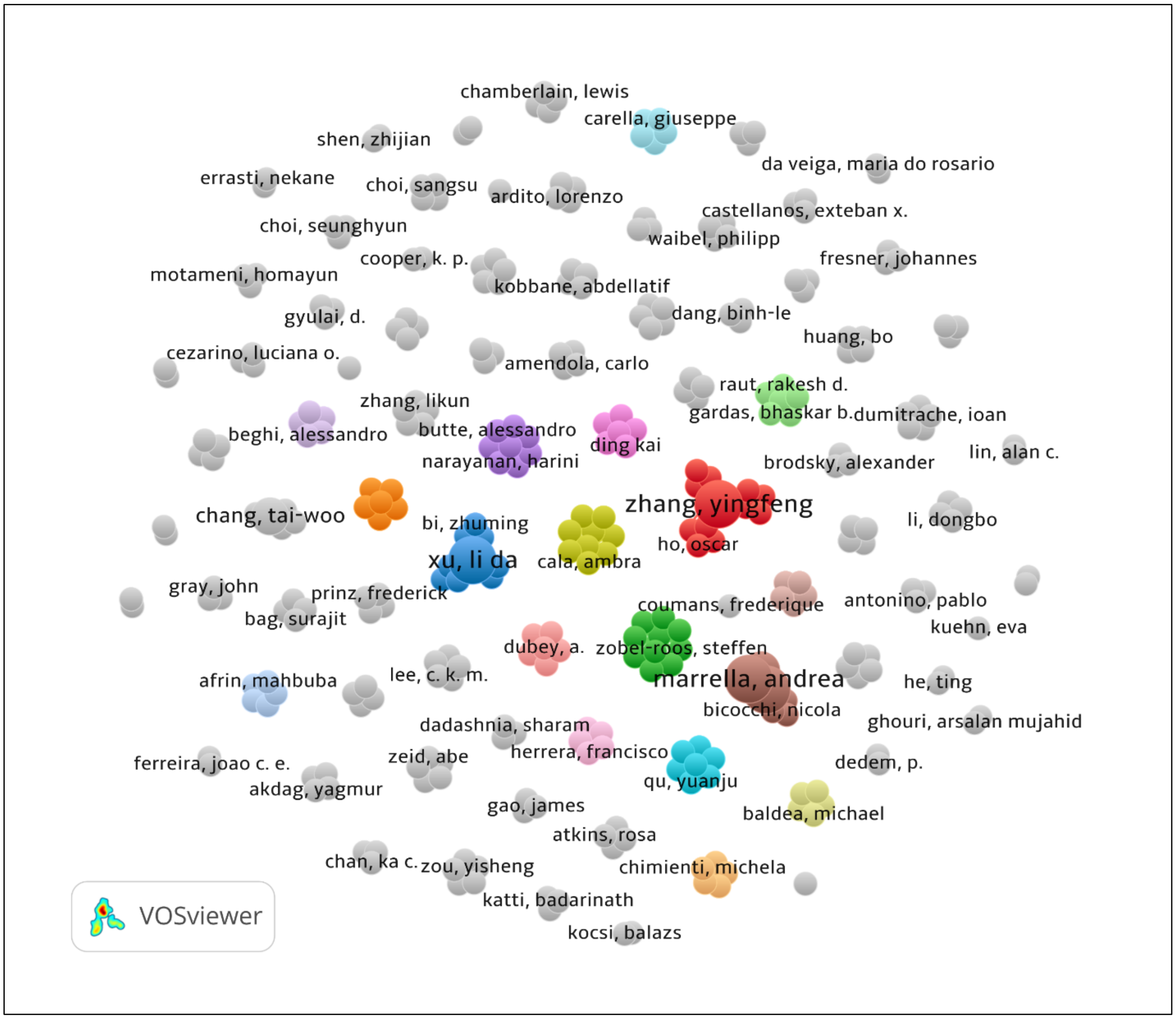


Figure 4. Co-authorship network of authors.

4. Analysis and discussion of the strategic diagrams

Process modelling in intelligent environments appeared for the first time in the literature in 2011, when Zhang et al. (2011) discuss real-time manufacturing applications through a smart objects gateway to model, integrate and manage intelligent applications on the shop floor in real time. Later, Duro-royo et al. (2015) propose a new workflow for direct additive manufacturing in heterogeneous structures, integrating physical and virtual data for monitoring and controlling materials and data in real time. Between 2011 and 2015 few documents present studies that relate process modelling and industry 4.0. In the first subperiod (Figure 5.a), the term 'optimization' stands out as a driving theme due to its greater centrality and strong density. Works related to this cluster present an overview of new technologies for simulation, optimization and automation of processes in computer numerical control (Li et al. 2015), and Menascé et al. (2015) present an autonomic framework to map processes and predict variables such as machine usage, energy consumption and manufacturing times in smart factory processes.

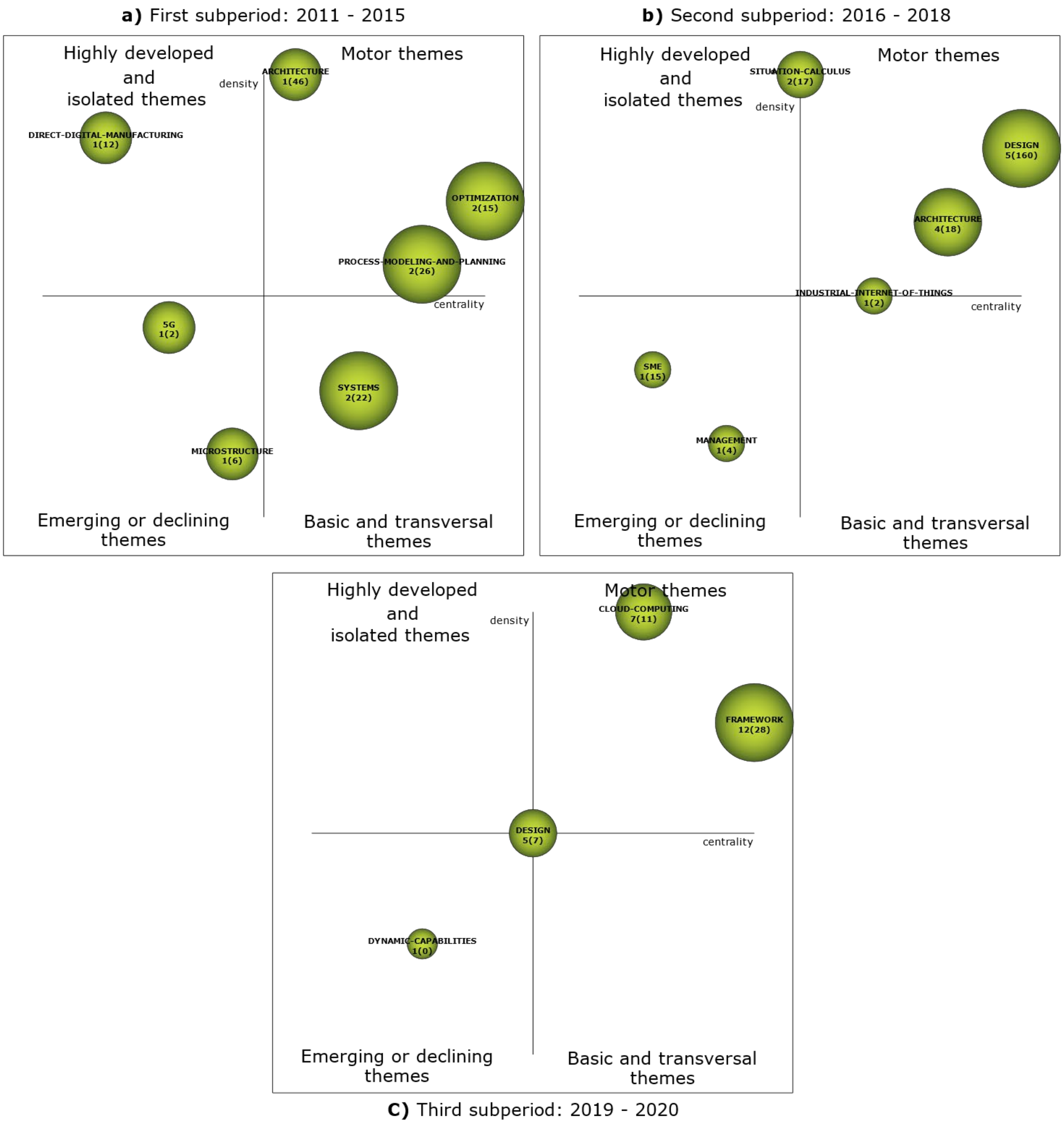


Figure 5. Strategic diagrams (2011–2020) (Source: SciMAT).

In the second subperiod (2016 – 2018) (Figure 5.b) the term 'design' stands out for its high density and strong centrality. In this cluster, the work of Yang et al. (2018) describes a meta-model that considers information from the manufacturing process supported by Unified Modelling Language, while Moghaddam and Nof (2018) present a framework for Cloud Manufacturing systems for better integration of services and manufacturing components in collaborative network. In this subperiod, Xu et al. (2018) reiterate that the integration between different process models to manage workflows in industry 4.0 has received little attention, strengthening the need for studies that seek to integrate heterogeneous models for intelligent environments. Still in this subperiod, the term 'architecture' is again discussed through works that proposes a business process management system (BPMS) extended to deal with uncertain processes (Saraeian et al. 2018). García et al. (2018) combine UML and IEC-61499 to assist in the control of industrial processes, while Nagadi et al. (2018) propose a hybrid simulation-based structure for intelligent manufacturing systems.

In the third subperiod (2019 – 2020) (Figure 5.c), with strong centrality and high density, studies related to the 'framework' cluster present proposals aimed at implementing emerging technologies. Qu et al. (2019) suggest a framework based on Business Process Reengineering to improve the organization's Enterprise information system and business process management, while Barenji et al. (2019) present a framework for cyber-physical systems based on UML. Viriyasitavat et al. (2019) study emerging technologies to development of BPM (business process management) tools in the digital economy, and Cheng et al. (2019) present an extension of the BPMN for modelling and implanting sensors. In this subperiod, the 'cloud-computing' cluster is mainly related to the deployment of cloud computing and its integration with other technologies, as can be seen in the work of Ardito et al. (2019) and Cui et al. (2020). Other works in this subperiod focus on the sustainable side of industry 4.0 processes (Sénéchal and Trentesaux 2019; Raut et al. 2019) and on the adoption of other emerging technologies (Lee et al. 2019; Liu et al. 2019; Kamble et al. 2019).

5. Analysis of thematic areas

Figure 6 presents the thematic evolution of the field of research of process modelling for industry 4.0. It is possible to observe in the first and second subperiod the strong development of the cluster 'architecture', which demonstrates the efforts of researchers to carry out works that used process modelling in contexts of industry 4.0 for real-time data collection (Zhang et al. 2011), help upper management implement and assess industry 4.0 (Nagadi et al. 2018), and enhance decision-making (Saraeian et al. 2018). The 'framework' cluster in the third subperiod represents a higher level of maturity in the process modelling field and its importance for the development of smart factories, as according to Kipper et al. (2019) the implementation of industry 4.0 in organizations has as one of the main challenges the development of frameworks in order to help managers to implement new technologies. The appearance of the cluster 'management' and its co-occurrence with the 'cloud-computing' and 'optimization' demonstrates efforts to optimize the management of organizational processes using cloud computing. In addition, the 'SME' cluster presents research efforts to develop process modelling not only at big companies, but also in small and medium enterprises (Rodič 2017), which are the kind of companies that suffer the most to implement industry 4.0 technologies, not only because of the lack of formalized processes, but also due to the low-cost systems implemented as well as lack of ICT knowledge (Dassisti et al. 2019).

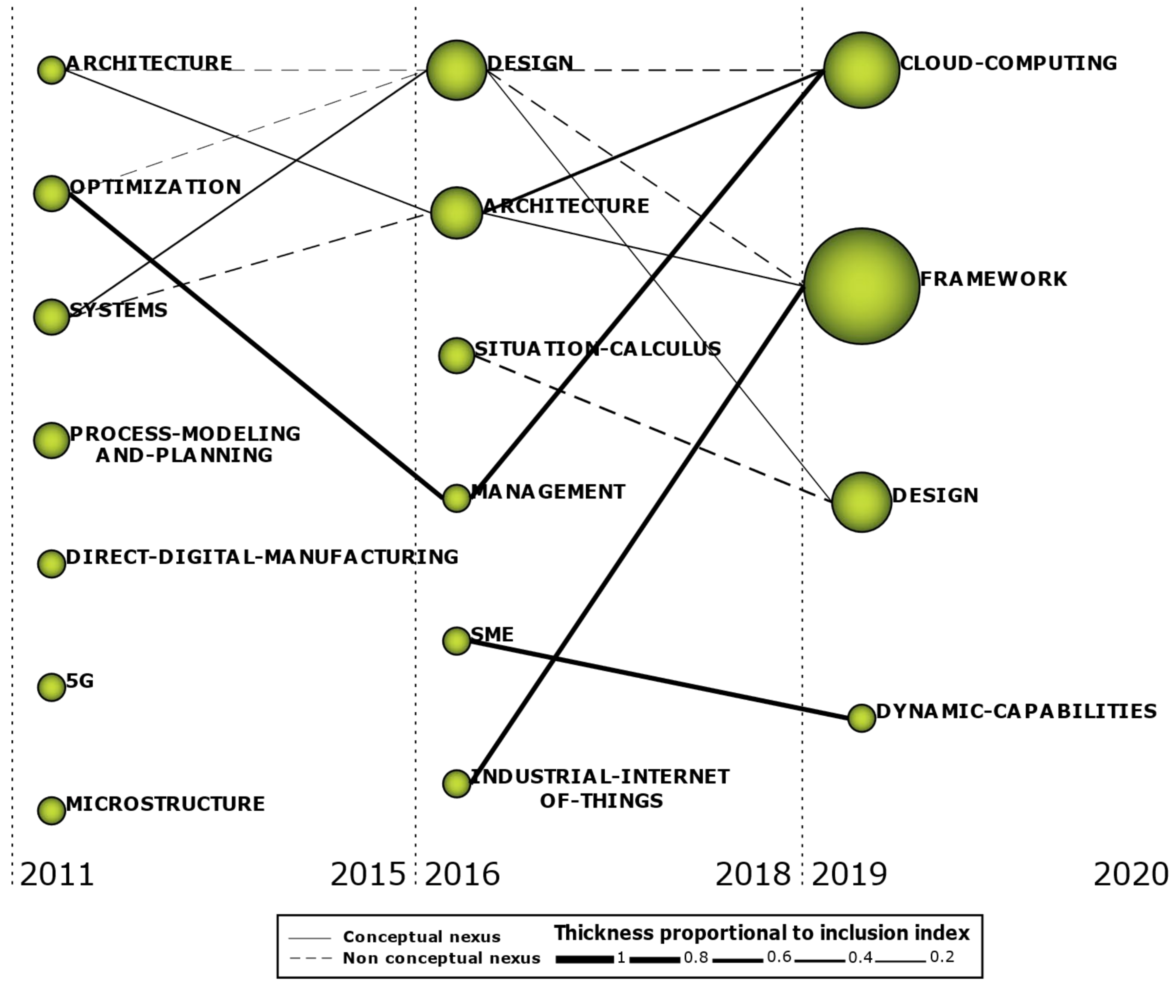


Figure 6. Thematic areas (Source: SciMAT).

The motor themes of the last subperiod shows the relationship between other important themes (Figure 7). The studies that discuss design (a) are related to interoperability, modelling, quality, support and sustainability, among others. Cloud-computing (b) in sequence is discussed together with other technologies, such as Internet of Things, Big Data and Big Data Analytics, but it is also related to life cycle, management and service, among other related terms. The cluster framework (c) meets the mentioned works, showing relationships with cyber-physical systems, performance, systems and technology, also having a bias with innovation, time, challenges and future, among others.

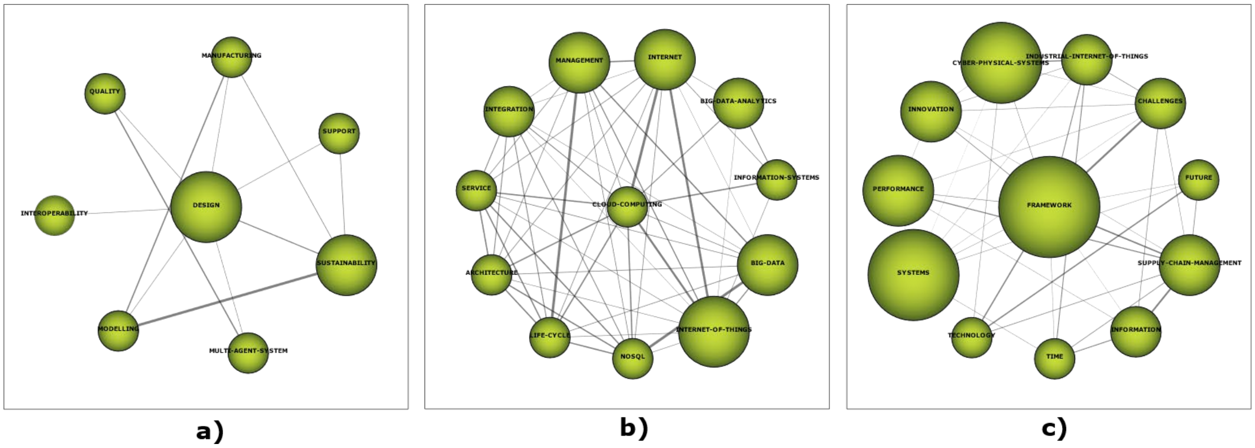


Figure 7 - Intellectual structure of motor themes from 2019 - 2020.

6. Main challenges, perspectives and future research

The process modelling thematic is fragmented in different works, with a little uniformity in concepts and divergent opinions on the use of traditional modelling languages. Some authors argue that traditional languages do not meet the requirements imposed by digital transformation (Seiger et al. 2015) and studies should seek to incorporate heterogeneous models into a common structure to integrate workflow management systems and industry 4.0 (Xu et al. 2018). Other authors developed adaptations and extensions in modelling languages, as it can see at studies of Du et al. (2018) and Cheng et al. (2019). Therefore, the need of further studies arises for a better understanding of the process modelling languages used to represent the complex processes of intelligent factories (Xu et al. 2018). In addition, Hwang et al. (2017), Kumar et al. (2018) and Kipper et al. (2019) point out the need for studies related to impacts and changes in organizational processes due to the insertion of industry 4.0 technologies.

While well-modelled, monitored and controlled processes reduce costs (Hammer 2015), on the other hand, modelling problems have a tendency to cause serious errors and losses in organizational processes (Geiger et al. 2018), highlighting the necessity for organizations to compromise to mapping and modelling their processes to become intelligent factories (Savastano et al. 2019). Although the increasing number of professionals in this field (Turetken and Demirors 2013), there is still a lack of modelers with deeper knowledge about the different modelling languages (Rosemann 2006). These professionals are responsible to identify the language which best represents the processes of the organization (Dani et al. 2019). Other difficulties are related to complex and varied notations, semantics and modelling elements (Leopold et al. 2015). This difficulty for creation and comprehensibility of modelling represents an error rate of around 20% in business practices related to process modelling (Dikici et al. 2018).

This work highlights the need for in-depth research to identify the process modelling languages that meet the needs of the factories of the future. In this context, more surveys and case studies should be carried out in companies that apply process modelling to understanding the applicability of these languages in smart environments. New frameworks can develop extensions of current modelling, and new modelling languages must involve the dynamism and parallelism of the factories of the future. Besides, more research must be performed in order develop the modelling of intelligent processes in small and medium enterprises. Furthermore, the low number of documents demonstrates the little maturity of the research field, highlighting the need for new and in-depth studies in the area to assist organizations in the digital transformation.

7. Conclusion

The objective of this paper was to understand the evolution structure of process modelling for industry 4.0 with the support of SciMAT and VOSviewer software. Through this research we identified current topics, authors in the field, co-authorship of researchers, as well as the development of a map of the field of study, identifying productive themes with great scientific impact and pointing the main challenges, perspectives and future research. The number of publications are increasing considerably over the years. The scientific evolution presented 17 clusters whereby the most representative themes are: 'design', 'framework' and ‘cloud computing'. Few identified works use traditional modelling languages in the context of the fourth industrial revolution. Most of the studies are aimed at developing new frameworks or integrating languages with other techniques for mapping and modelling organizational processes. The analysis of the clusters shows some of the challenges related to process modelling and implementation of emerging technologies, and the concern with the design and development of frameworks that meet the needs of the fourth industrial revolution. This research is limited to analyzing only the Web of Science database. Only documents articles and reviews in English were also used, although other documents may present relevant topics and research. In addition, some studies may have been ignored, since the work linked to the most important clusters, which are characterized as motor themes in the strategic diagrams, with the purpose of reducing the bias of the researchers on the chosen works. Further works can be developed by analyzing databases such as Scopus, Science Direct, among others. Future works can be performed in order to strengthening research networks between network of authors to support the implementation of industry 4.0 in companies.

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References

Ahmed, F. D., and Majid, M. A., Towards agent-based petri net decision making modelling for cloud service composition: A literature survey, *Journal of Network and Computer Applications*, *130*, 14-38, 2019.

Alissa, K., Reid, J., and Dawson, E., SPCC: a security policy compliance checker plug-in for YAWL, *International Journal of Business Process Integration and Management*, *9*(1), 22-31, 2018.

Alotaibi, Y., and Liu, F., Survey of business process management: challenges and solutions, *Enterprise Information Systems*, *11*(8), 1119-1153, 2017.

Amjad, A., Azam, F., Anwar, M. W., Butt, W. H., and Rashid, M., Event-driven process chain for modeling and verification of business requirements–a systematic literature review, *IEEE Access*, *6*, 9027-9048, 2018.

Ardito, L., Petruzzelli, A. M., Panniello, U., and Garavelli, A. C., Towards Industry 4.0, *Business Process Management Journal*, 2019.

Arévalo, C., Escalona, M. J., Ramos, I., and Domínguez-Muñoz, M., A metamodel to integrate business processes time perspective in BPMN 2.0, *Information and Software Technology*, *77*, 17-33, 2016.

Barenji, R. V., Akdag, Y., Yet, B., and Oner, L., Cyber-physical-based PAT (CPbPAT) framework for Pharma 4.0, *International journal of pharmaceutics*, *567*, 118445, 2019.

Bauer, W., Hämmerle, M., Schlund, S., and Vocke, C., Transforming to a hyper-connected society and economy–towards an "Industry 4.0", *Procedia Manufacturing*, *3*, 417-424, 2015.

Buer, S. V., Strandhagen, J. O., and Chan, F. T., The link between Industry 4.0 and lean manufacturing: mapping current research and establishing a research agenda, *International Journal of Production Research*, *56*(8), 2924-2940, 2018.

Cheng, Y., Zhao, S., Cheng, B., Chen, X., and Chen, J., Modeling and deploying IoT-aware business process applications in sensor networks, *Sensors*, *19*(1), 111, 2019.

Cobo, M. J., Jürgens, B., Herrero-Solana, V., Martínez, M. A., and Herrera-Viedma, E., Industry 4.0: a perspective based on bibliometric analysis, Procedia computer science, 139, 364-371, 2018.

Cobo, M. J., López-Herrera, A. G., Herrera-Viedma, E., and Herrera, F., SciMAT: A new science mapping analysis software tool, *Journal of the American Society for Information Science and Technology*, *63*(8), 1609-1630, 2012.

Cui, Y., Kara, S., and Chan, K. C., Manufacturing big data ecosystem: A systematic literature review, *Robotics and Computer-Integrated Manufacturing*, *62*, 101861, 2020.

Dani, V. S., Freitas, C. M. D. S., and Thom, L. H., Ten Years of Visualization of Business Process Models: A Systematic Literature Review, *Computer Standards & Interfaces*, 2019.

Dassisti, M., Giovannini, A., Merla, P., Chimienti, M., and Panetto, H., An approach to support Industry 4.0 adoption in SMEs using a core-metamodel, *Annual Reviews in Control*, *47*, 266-274, 2019.

De Oca, I. M. M., Snoeck, M., Reijers, H. A., and Rodríguez-Morffi, A., A systematic literature review of studies on business process modeling quality, *Information and Software Technology*, *58*, 187-205, 2015.

Dikici, A., Turetken, O., and Demirors, O., Factors influencing the understandability of process models: A systematic literature review, *Information and Software Technology*, *93*, 112-129, 2018.

Du, S., Wu, P., Wu, G., Yao, C., and Zhang, L., The collaborative system workflow management of industrial design based on hierarchical colored petri-net, *IEEE Access*, *6*, 27383-27391, 2018.

Duro-Royo, J., Mogas-Soldevila, L., and Oxman, N., Flow-based fabrication: An integrated computational workflow for design and digital additive manufacturing of multifunctional heterogeneously structured objects, *Computer-Aided Design*, *69*, 143-154, 2015.

Falagas, M. E., Kouranos, V. D., Arencibia-Jorge, R., and Karageorgopoulos, D. E., Comparison of SCImago journal rank indicator with journal impact factor, *The FASEB journal*, *22*(8), 2623-2628, 2008.

Furstenau, L. B., Santos, T. C. W., Kipper, L. M., Dal Forno, A. J., and Sott, M. K., Proposta de estrutura para a gestão do processo de precificação de produtos de uma empresa de base tecnológica, Anais do Encontro Nacional de Engenharia de Produção – Enegep, 2019. https://dx.doi.org/10.14488/enegep2019_ti_st_290_634_38321

Fynes, B., Coughlan, P., Brennan, L., Ferdows, K., Godsell, J., Golini, R., ... and Taylor, M., Manufacturing in the world: where next?, *International Journal of Operations & Production Management*, 2015.

García, C. A., Castellanos, E. X., and García, M. V., UML-Based Cyber-Physical Production Systems on Low-Cost Devices under IEC-61499, *Machines*, *6*(2), 22, 2018.

Geiger, M., Harrer, S., Lenhard, J., and Wirtz, G., BPMN 2.0: The state of support and implementation, *Future Generation Computer Systems*, *80*, 250-262, 2018.

Hammer, M., What is business process management?, In *Handbook on business process management 1* (pp. 3-16). Springer, Berlin, Heidelberg, 2015.

Hwang, G., Lee, J., Park, J., and Chang, T. W., Developing performance measurement system for Internet of Things and smart factory environment, *International journal of production research*, *55*(9), 2590-2602, 2017.

Kagermann, H., Helbig, J., Hellinger, A., and Wahlster, W., Recommendations for implementing the strategic initiative INDUSTRIE 4.0: Securing the future of German manufacturing industry, *Final Report of the Industrie 4.0 Working Group*, Forschungsunion, 2013.

Kamble, S. S., Gunasekaran, A., Parekh, H., and Joshi, S., Modeling the internet of things adoption barriers in food retail supply chains, *Journal of Retailing and Consumer Services*, *48*, 154-168, 2019.

Kipper, L. M., Furstenau, L. B., Hoppe, D., Frozza, R., and Iespen, S., Scopus scientific mapping production in industry 4.0 (2011–2018): a bibliometric analysis, *International Journal of Production Research*, 1-24, 2019.

Kipper, L. M., Nara, E. O. B., Siluk, J. C. M., Caurio, C., Silva, A. L. E., and Silva, J. I. D., Organisational management through performance indicators, International Journal of Services and Operations Management, 34(4), 447-464, 2019a.

Kumar, A. S., and Iyer, E., An industrial IoT in engineering and manufacturing industries – benefits and challenges, *International Journal of Mechanical and Production Engineering Research and Dvelopment* (IJMPERD), v. 9, n 2, p. 151-160, 2019.

Kumar, S., Purohit, B. S., Manjrekar, V., Singh, V., and Lad, B. K., Investigating the value of integrated operations planning: A case-based approach from automotive industry, *International Journal of Production Research*, *56*(22), 6971-6992, 2018.

Lee, C. K. M., Lin, B., Ng, K. K. H., Lv, Y., and Tai, W. C., Smart robotic mobile fulfillment system with dynamic conflict-free strategies considering cyber-physical integration, *Advanced Engineering Informatics*, *42*, 100998, 2019.

Leopold, H., Mendling, J., and Günther, O., Learning from quality issues of BPMN models from industry, *IEEE Software*, *33*(4), 26-33, 2015.

Li, Y., Lee, C. H., and Gao, J., From computer-aided to intelligent machining: recent advances in computer numerical control machining research, *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, *229*(7), 1087-1103, 2015.

Liao, Y., Deschamps, F., Loures, E. D. F. R., and Ramos, L. F. P., Past, present and future of Industry 4.0-a systematic literature review and research agenda proposal *International journal of production research*, *55*(12), 3609-3629, 2017.

Liu, B., Zhang, Y., Zhang, G., and Zheng, P., Edge-cloud orchestration driven industrial smart product-service systems solution design based on CPS and IioT, *Advanced Engineering Informatics*, *42*, 100984, 2019.

López-Robles, J. R., Otegi-Olaso, J. R., Gómez, I. P., and Cobo, M. J., 30 years of intelligence models in management and business: A bibliometric review, *International journal of information management*, *48*, 22-38, 2019.

Menascé, D. A., Krishnamoorthy, M., and Brodsky, A., Autonomic smart manufacturing, *Journal of Decision Systems*, *24*(2), 206-224, 2015.

Moghaddam, M., and Nof, S. Y., Collaborative service-component integration in cloud manufacturing, *International Journal of Production Research*, *56*(1-2), 677-691, 2018.

Nagadi, K., Rabelo, L., Basingab, M., Sarmiento, A. T., Jones, A., and Rahal, A., A hybrid simulation-based assessment framework of smart manufacturing systems, *International Journal of Computer Integrated Manufacturing*, *31*(2), 115-128, 2018.

Pourmirza, S., Peters, S., Dijkman, R., and Grefen, P., A systematic literature review on the architecture of business process management systems, *Information Systems*, *66*, 43-58, 2017.

Qu, Y., Ming, X., Ni, Y., Li, X., Liu, Z., Zhang, X., and Xie, L., An integrated framework of enterprise information systems in smart manufacturing system via business process reengineering, *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, *233*(11), 2210-2224, 2019.

Raut, R. D., Mangla, S. K., Narwane, V. S., Gardas, B. B., Priyadarshinee, P., and Narkhede, B. E., Linking big data analytics and operational sustainability practices for sustainable business management, *Journal of cleaner production*, *224*, 10-24, 2019.

Reis, L. V., Kipper, L. M., Velásquez, F. D. G., Hofmann, N., Frozza, R., Ocampo, S. A., and Hernandez, C. A. T., A model for Lean and Green integration and monitoring for the coffee sector, Computers and electronics in agriculture, 150, 62-73, 2018.

Rodič, B., Industry 4.0 and the new simulation modelling paradigm, *Organizacija*, *50*(3), 193-207, 2017.

Rosemann, M., Potential pitfalls of process modeling: part A, *Business Process Management Journal*, 2006.

Rumbaugh, J., Jacobson, I., and Booch, G., Unified modeling language reference manual, the.[Sl]: *Pearson Higher Education*, *Citado na*, 55, 2004.

Saraeian, S., Shirazi, B., and Motameni, H., Towards an extended BPMS prototype: Open challenges of BPM to flexible and robust orchestrate of uncertain processes, *Computer Standards & Interfaces*, *57*, 1-19, 2018.

Savastano, M., Amendola, C., Bellini, F., and D'Ascenzo, F., Contextual impacts on industrial processes brought by the digital transformation of manufacturing: a systematic review, *Sustainability*, *11*(3), 891, 2019.

Seiger, R., Keller, C., Niebling, F., and Schlegel, T., Modelling complex and flexible processes for smart cyber-physical environments, *Journal of Computational Science*, *10*, 137-148, 2015.

Sénéchal, O., and Trentesaux, D., A framework to help decision makers to be environmentally aware during the maintenance of cyber physical systems, *Environmental Impact Assessment Review*, *77*, 11-22, 2019.

Smith, L., and Owens, D., A Methodology for the Study of Unified Modeling Language, *Software engineering and CS Journal*, *12*(1), 2019.

Smith, M., Wolfe, T., Cook, A., and Avila, E.; Towards the Study of Unified Modeling Language, *Computer Science and Information Technology Journal*, *3*(1), 2019.

Strozzi, F., Colicchia, C., Creazza, A., and Noè, C., Literature review on the 'Smart Factory'concept using bibliometric tools, *International Journal of Production Research*, *55*(22), 6572-6591, 2017.

Tidrea, A., Korodi, A., and Silea, I., Cryptographic Considerations for Automation and SCADA Systems Using Trusted Platform Modules, *Sensors*, *19* (19), 4191, 2019.

Tortorella, G. L., Vergara, A. M. C., Garza-Reyes, J. A., and Sawhney, R., Organizational learning paths based upon industry 4.0 adoption: An empirical study with Brazilian manufacturers, International Journal of Production Economics, 219, 284-294, 2020.

Tupa, J., Simota, J., and Steiner, F., Aspects of risk management implementation for Industry 4.0, *Procedia Manufacturing*, *11*, 1223-1230, 2017.

Turetken, O., and Demirors, O., Business process modeling pluralized. In *International Conference on Subject-Oriented Business Process Management* (pp. 34-51), Springer, Berlin, Heidelberg, 2013.

Van Der Aalst, W. M., and Ter Hofstede, A. H., YAWL: yet another workflow language, *Information systems*, *30*(4), 245-275, 2005.

Van der Aalst, W. M., Formalization and verification of event-driven process chains, *Information and Software technology*, *41*(10), 639-650, 1999.

Viriyasitavat, W., Da Xu, L., Bi, Z., and Pungpapong, V., Blockchain and Internet of Things for Modern Business Process in Digital Economy—the State of the Art, *IEEE Transactions on Computational Social Systems*, *6*(6), 1420-1432, 2019.

Waltman, L., and Van Eck, N. J., A new methodology for constructing a publication-level classification system of science, *Journal of the American Society for Information Science and Technology*, *63*(12), 2378-2392, 2012.

Wortmann, A., Barais, O., Combemale, B., and Wimmer, M., Modeling languages in Industry 4.0: An extended systematic mapping study, *Software and Systems Modeling*, *19*(1), 67-94, 2019.

Xu, L. D., Xu, E. L., and Li, L., Industry 4.0: state of the art and future trends, *International Journal of Production Research*, *56*(8), 2941-2962, 2018.

Yang, B., Qiao, L., Cai, N., Zhu, Z., and Wulan, M., Manufacturing process information modeling using a metamodeling approach, *The International Journal of Advanced Manufacturing Technology*, *94*(5-8), 1579-1596, 2018.

Zarour, K., Benmerzoug, D., Guermouche, N., and Drira, K., A systematic literature review on BPMN extensions, *Business Process Management Journal*, 2019.

Zhang, Y., Huang, G. Q., Qu, T., Ho, O., and Sun, S., Agent-based smart objects management system for real-time ubiquitous manufacturing, *Robotics and Computer-Integrated Manufacturing*, *27*(3), 538-549, 2011.

Zhou, M., & Wu, N., *System modeling and control with resource-oriented Petri nets*, Crc Press, 2018.

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